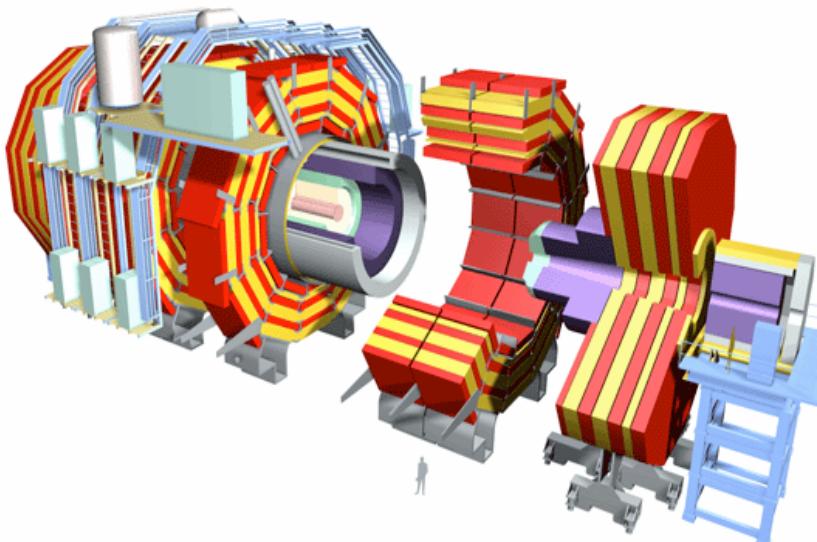




Hard Probe Capabilities of CMS@LHC

Gunther Roland
Massachusetts Institute of Technology



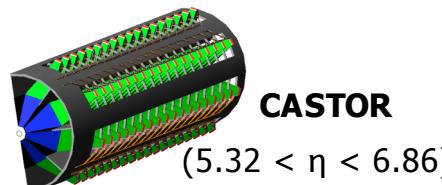
CMS HI groups: Adana, Athens, Basel, Budapest, CERN, Demokritos, Dubna, Ioannina, Kiev, Krakow, Los Alamos, Lyon, Minnesota, MIT, Moscow, Mumbai, N. Zealand, Protvino, PSI, Rice, Sofia, Strasbourg, U Kansas, Tbilisi, UC Davis, UI Chicago, U. Iowa, Yerevan, Warsaw, Zagreb



The Compact Muon Solenoid

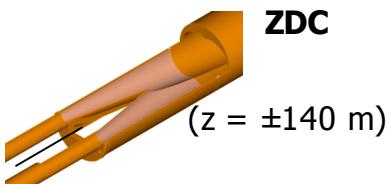


Forward calorimeters



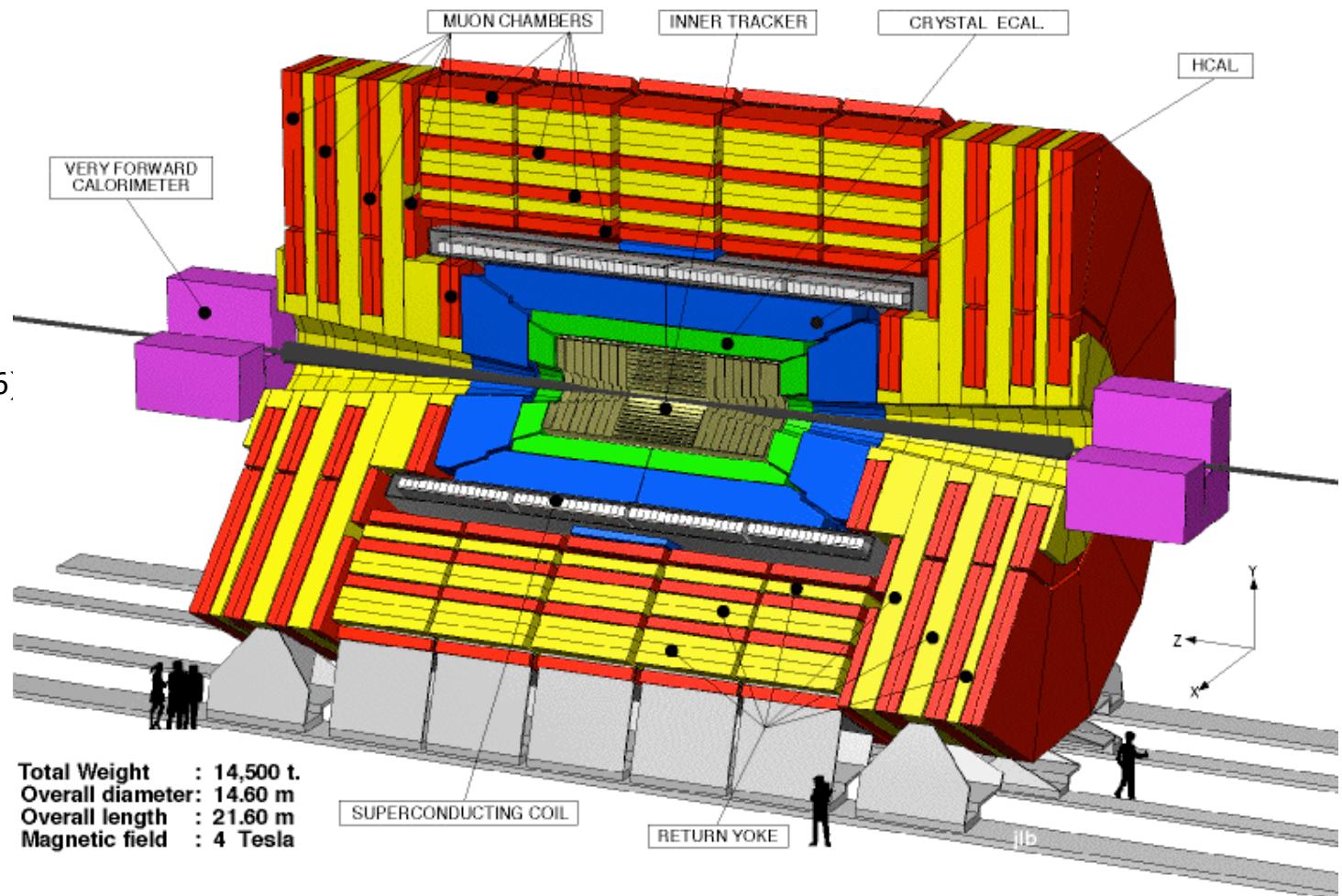
CASTOR

($5.32 < \eta < 6.86$)



ZDC

($z = \pm 140$ m)





CMS under construction



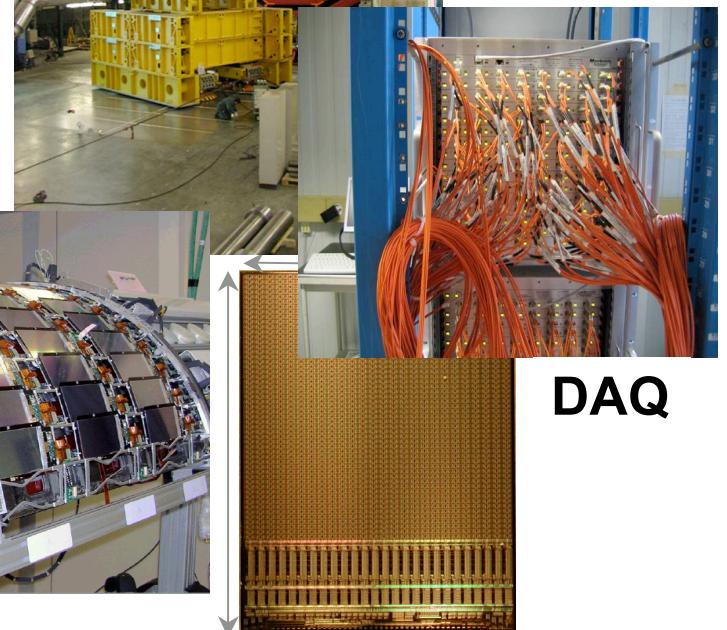
Muon Absorber



Magnet coil



Hadron
Calorimeter



Si tracker &
Pixels

Electromagnetic
Calorimeter

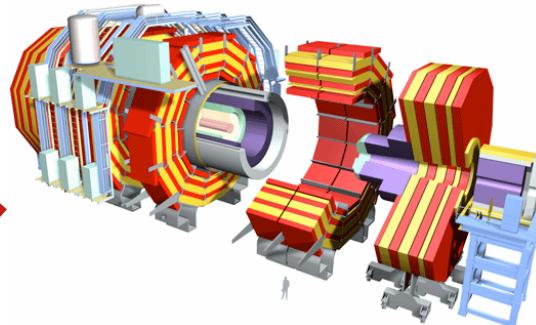


Gunther Roland

Hard Probes 2006



CMS as a Heavy Ion Experiment



CMS Goals in p+p

Origin of Mass - Higgs Mechanism

New Physics at TeV Scale

**Highly selective trigger (10^{-7})
on high p_T objects**

CMS Goals in HI

**Nature and properties of matter
at highest energy density**

Origin of Mass - Confinement

Global properties + hard probes

Challenge:
 ~ 25 pp collisions per
bunch crossing
**40MHz bunch crossing
frequency**

Capabilities

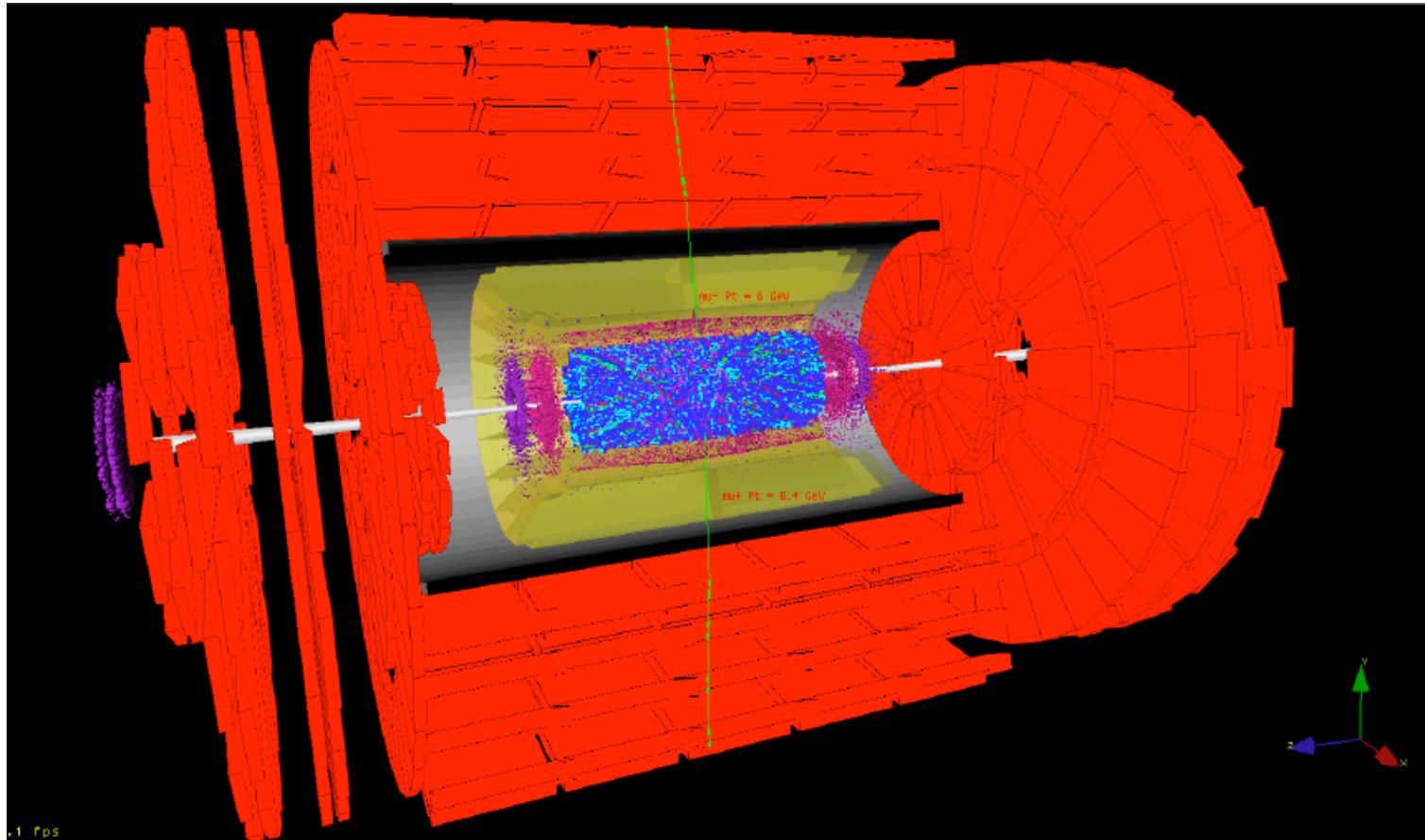
- Large coverage**
- High Precision Tracking**
- High Resolution Calorimetry**
- Lepton Identification**
- Large Bandwidth DAQ + Trigger**



Heavy Ion MC Event in CMS

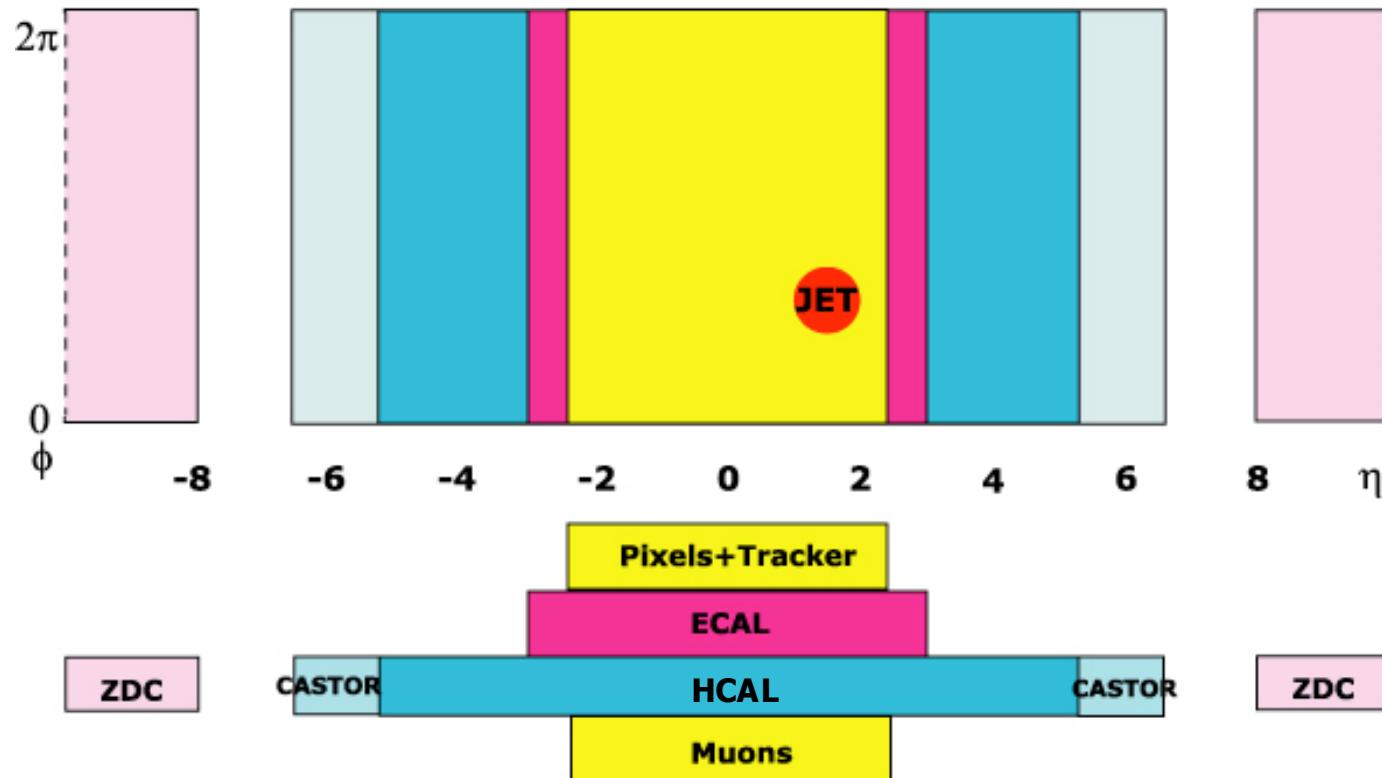


Pb+Pb event ($dN/dy = 3500$) with $Y \rightarrow \mu^+\mu^-$



**Pb+Pb event display: Produced in pp software framework
(simulation, data structures, visualization)**

Hermeticity and Coverage



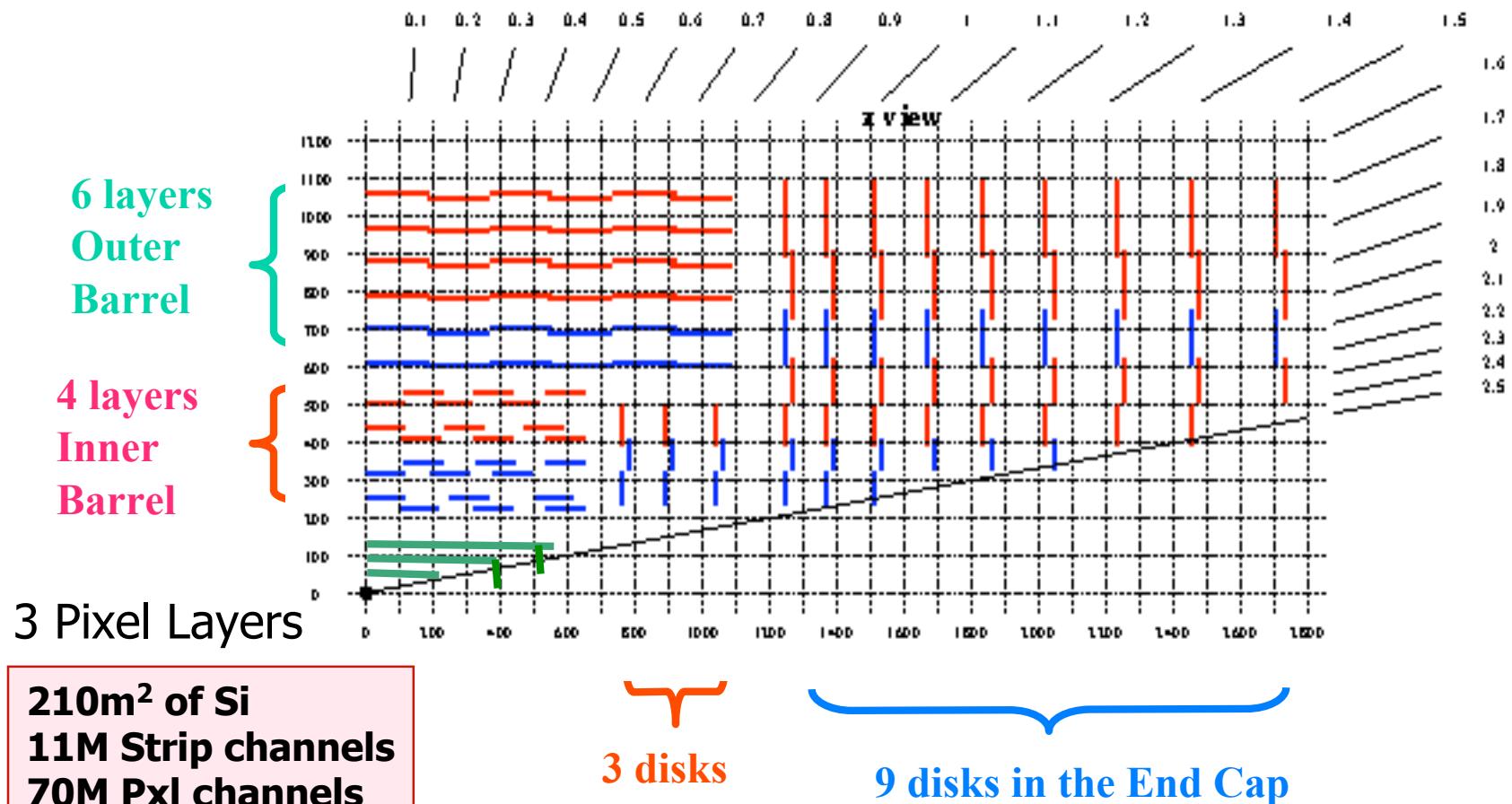
pp: Need “hermetic” coverage for E_T signatures

AA: Statistics for rare probes; “Global observables”; Access to different physical regimes (forward/low- x , “CGC”)

Tracker layout

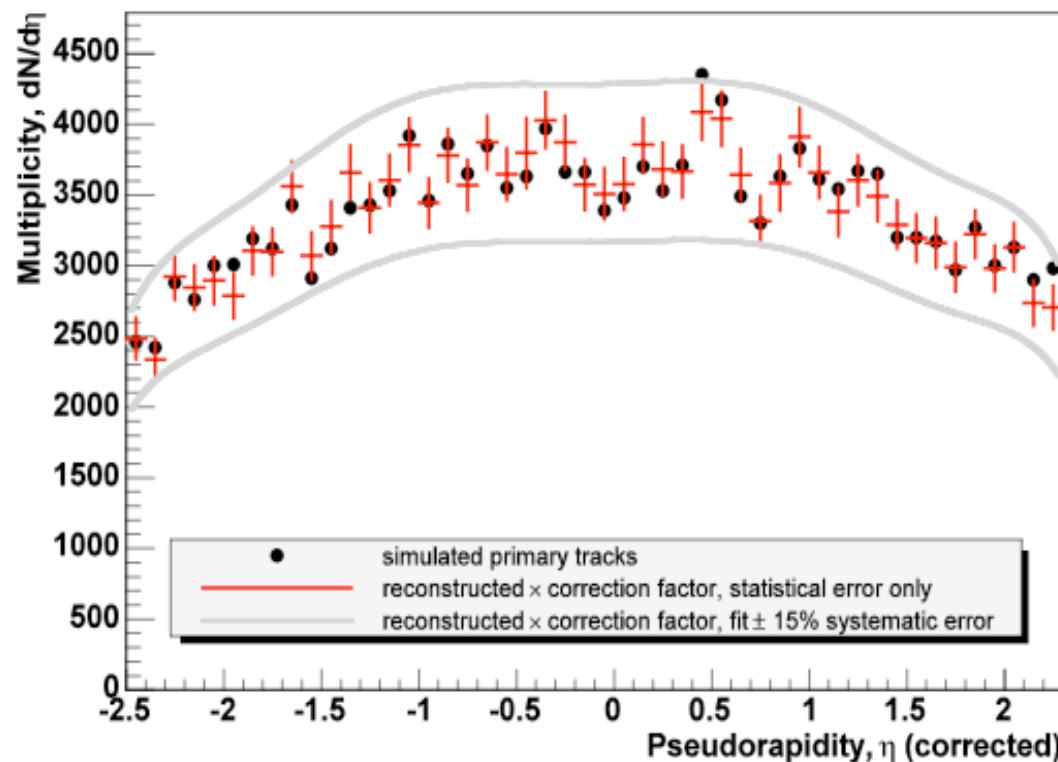
pp: 25 pp events on top of each other at design lumi; measure TeV muons; b-tagging; fast read-out

AA: tracking for large dN/dy; superb momentum resolution; charm and beauty from displaced vertices; Multiplicity measurement



Charged particle multiplicity

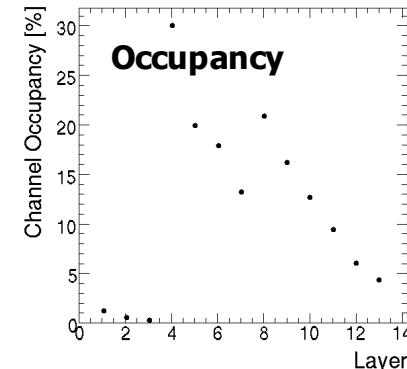
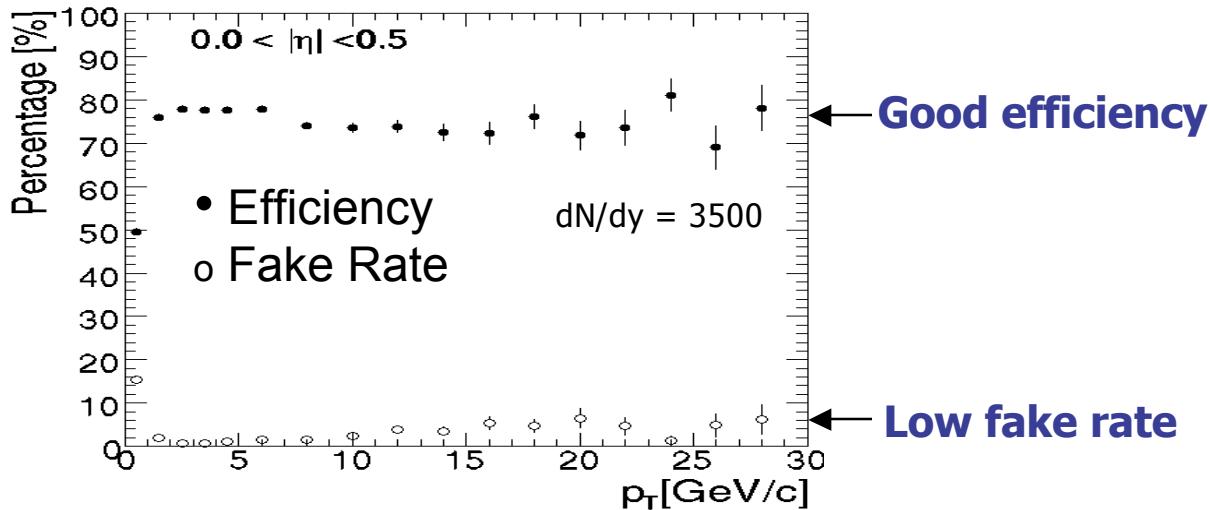
- High granularity pixel detectors ($100 \times 150 \mu\text{m}^2$)
- Pulse height measurement reduces background
- Very low p_T reach, $p_T > 26 \text{ MeV}$ (counting hits)



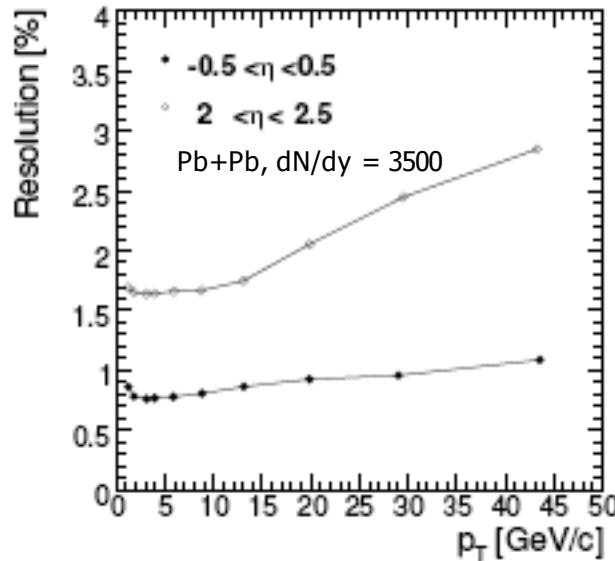
Will be one of the first results,
important for initial energy density, saturation



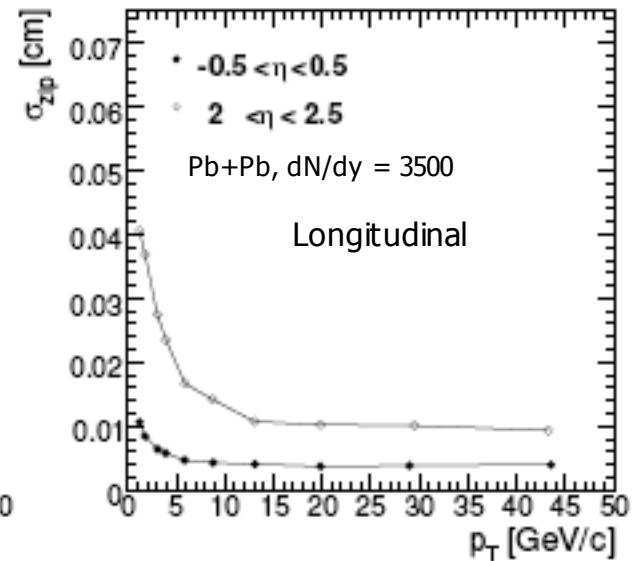
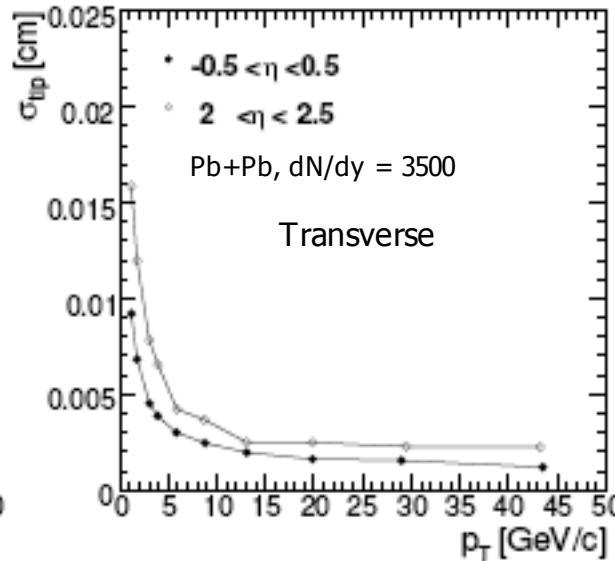
Tracking in Heavy Ion Collisions



World's best
momentum resolution



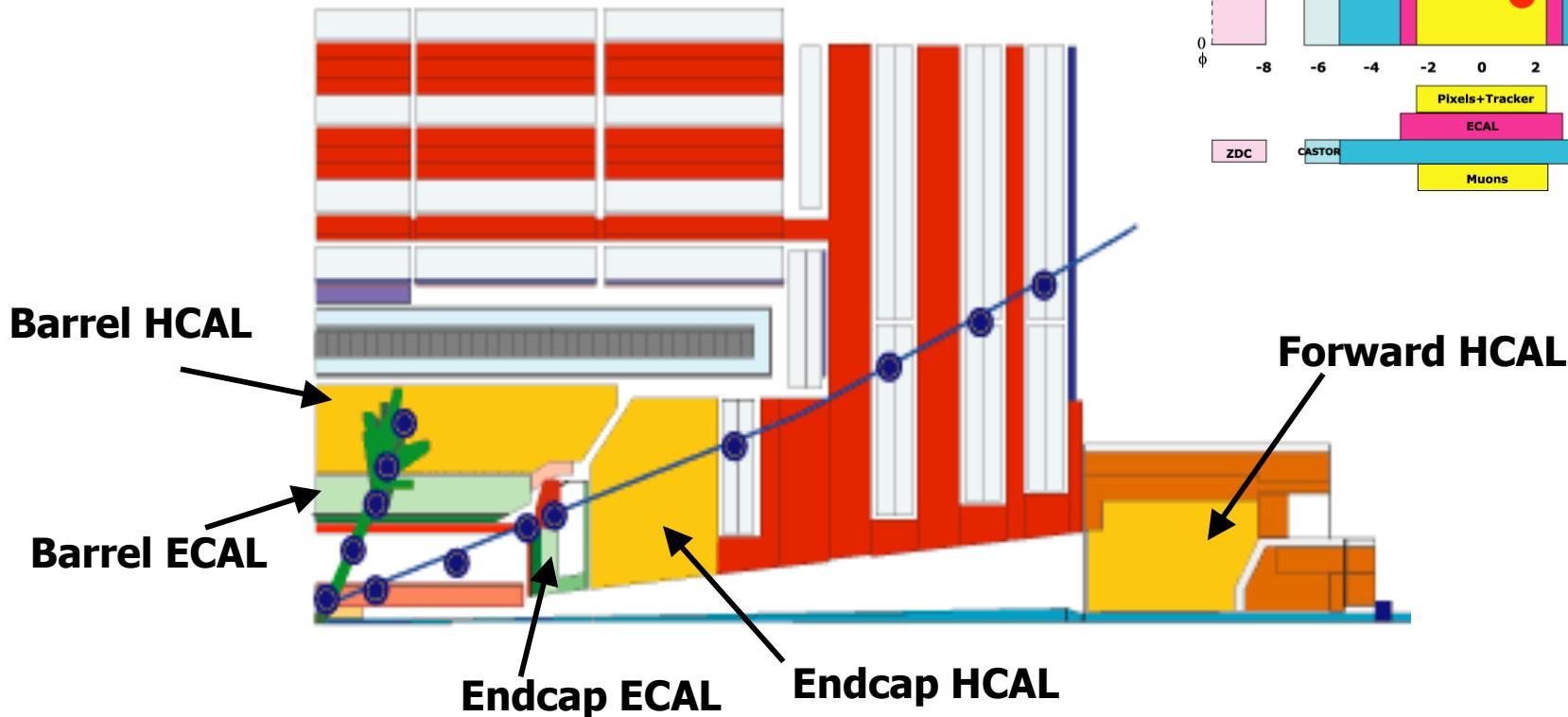
Excellent impact
parameter resolution



Heavy Flavor
tagging



CMS Calorimetry

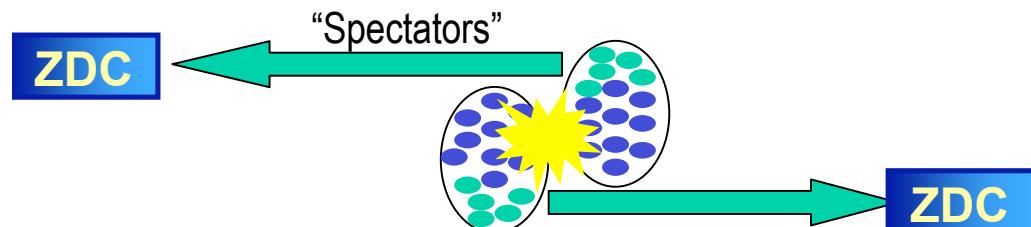


pp: High granularity; high resolution; hermetic coverage; fast readout

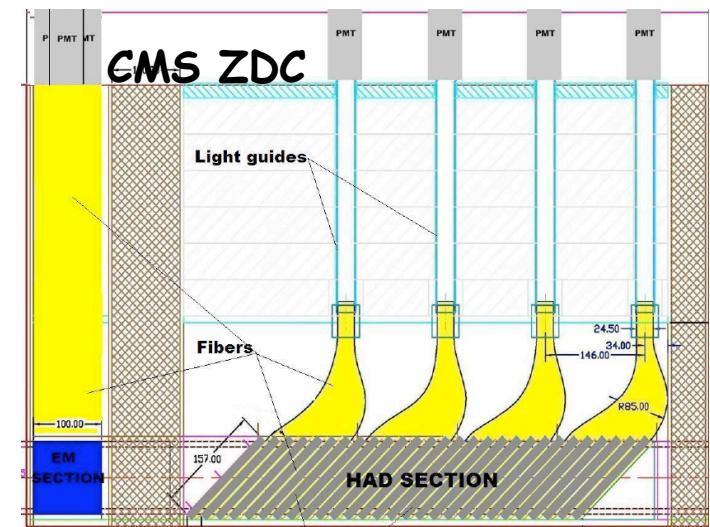
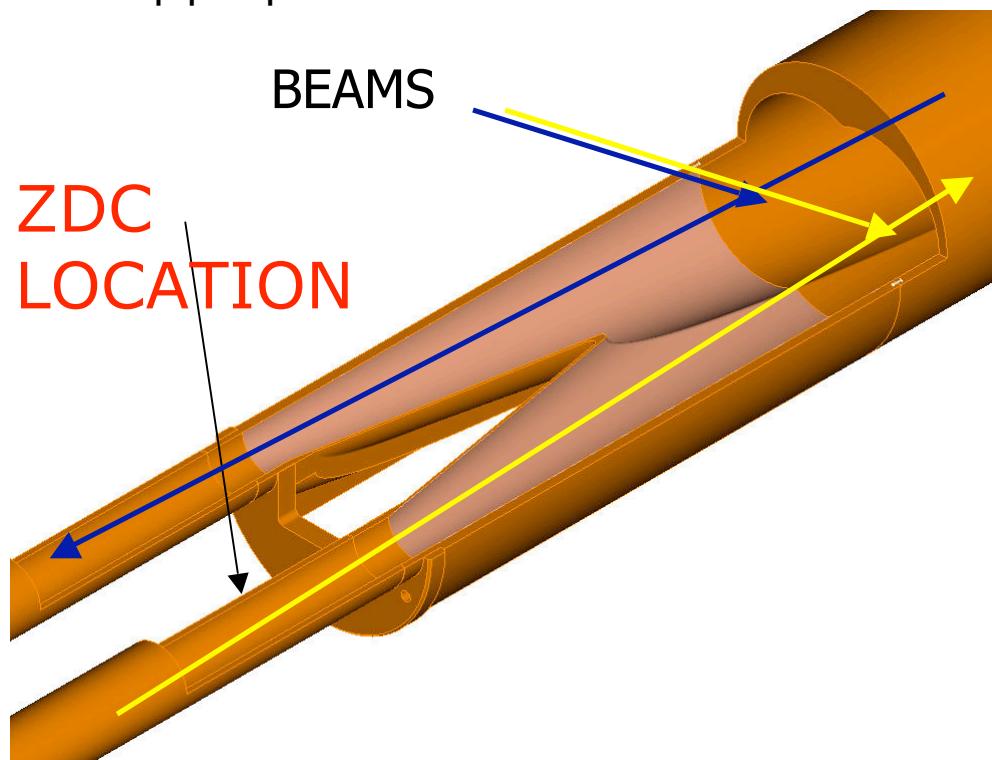
AA: New capability: Jets + energy flow over large y -range and 2π



Zero Degree Calorimetry for CMS

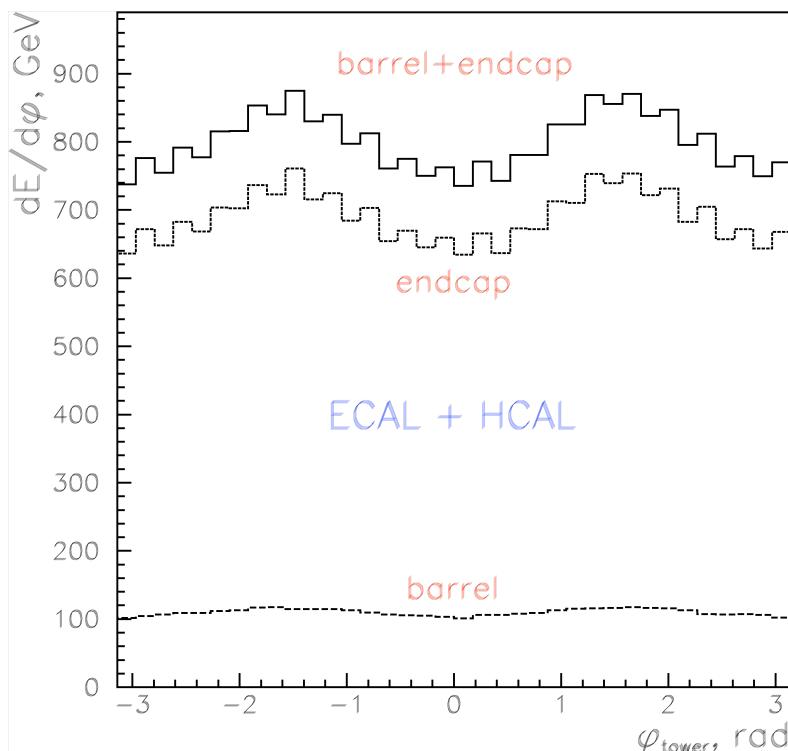


Beam pipe splits 140 m from IR



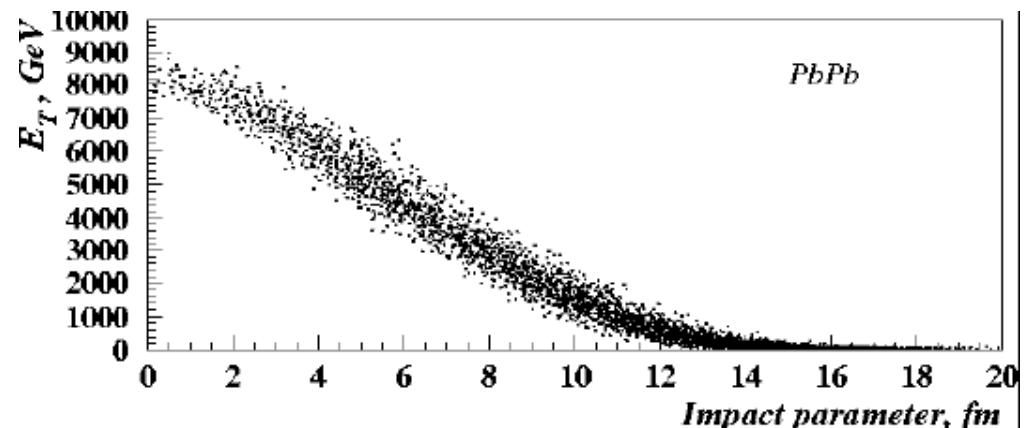
Tungsten-quartz fibre structure
Electromagnetic section: $19\lambda_0$
Hadronic section $5.6\lambda_0$
Rad. hard to »20 Grad (AA, pp low lum)
Energy resolution: »10% at 2.75 TeV
Position resolution: »2 mm (EM sect.)

Single Pb+Pb event, $b=6\text{fm}$



Event plane resolution $\sigma \sim 0.1 \text{ rad}$

Energy in forward hadron calo

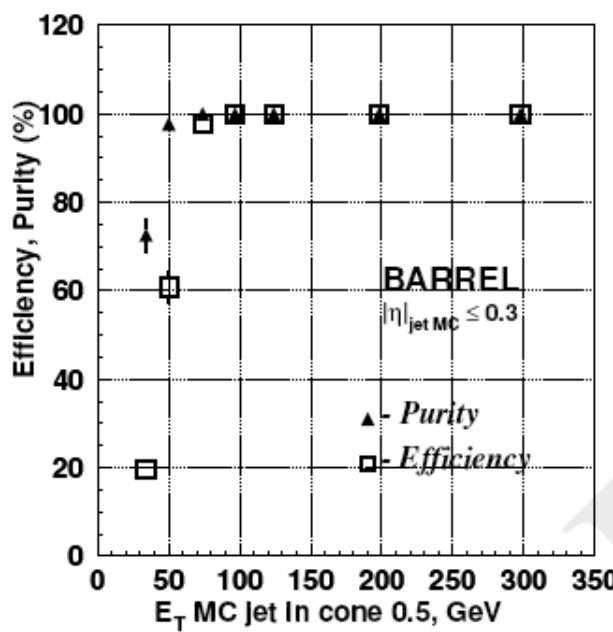
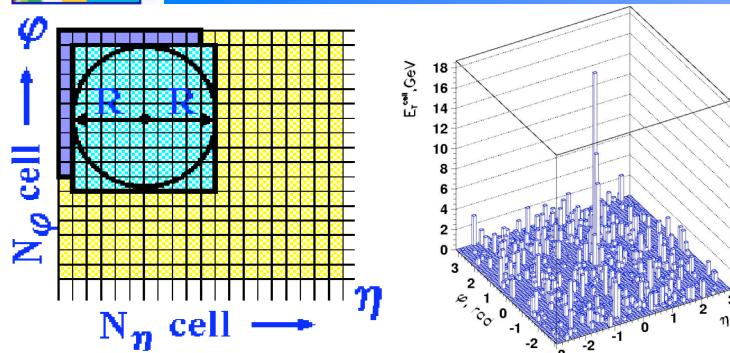


Event characterization from Calorimeters

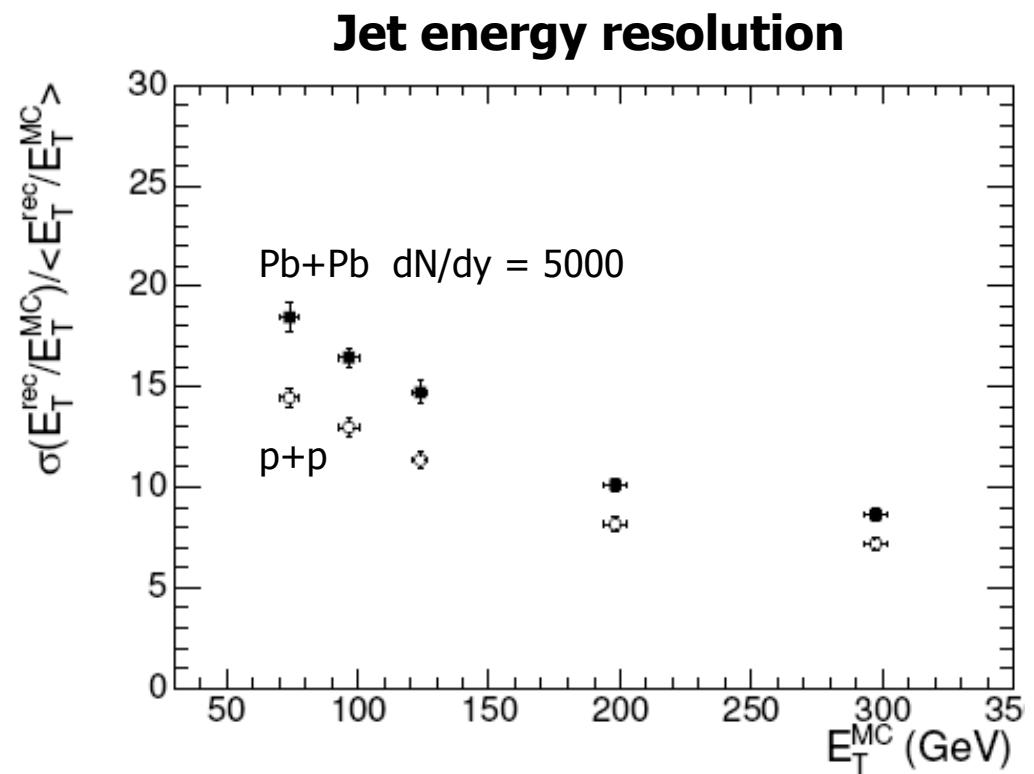
- Centrality
- Reaction plane
- Available in High Level Trigger



Calorimetric Jet reconstruction

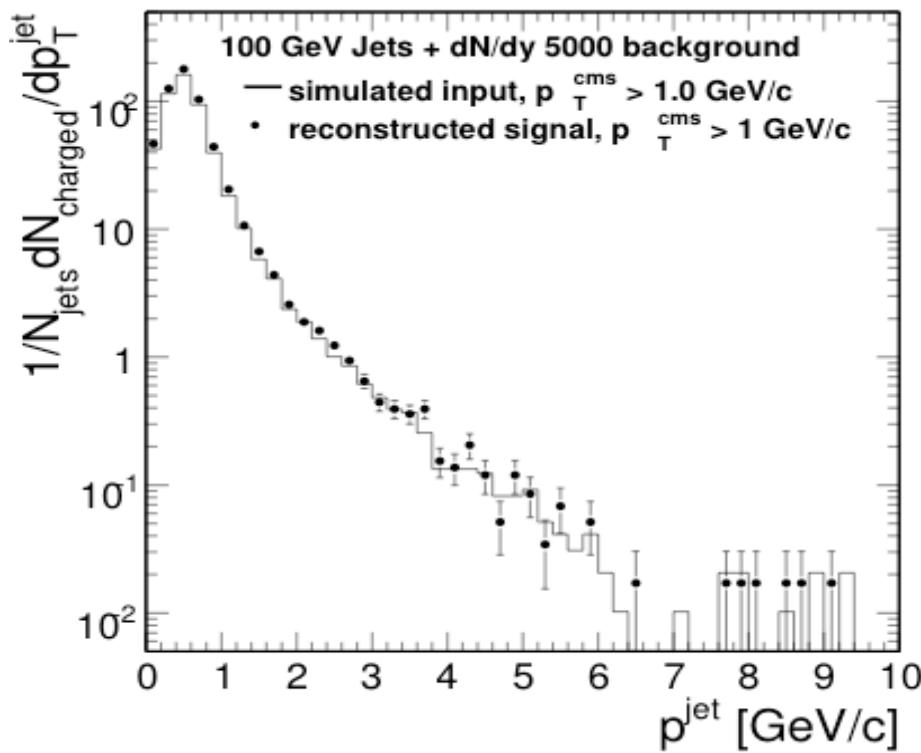


Iterative cone finder
with background subtraction

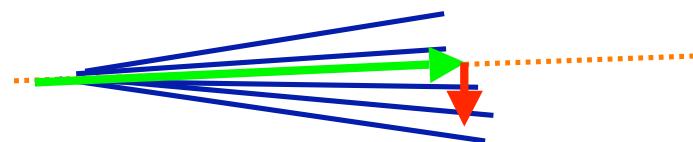
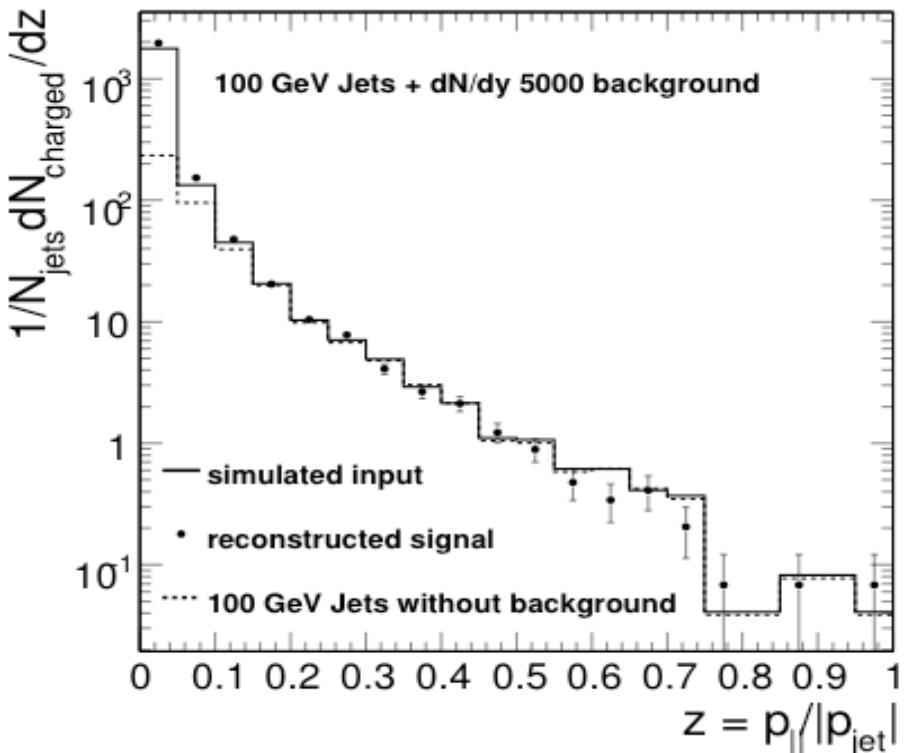


Jet spatial resolution: $\sigma(\phi_{\text{rec}} - \phi_{\text{gen}}) = 0.032$; $\sigma(\eta_{\text{rec}} - \eta_{\text{gen}}) = 0.028$

Longitudinal momentum fraction z
along the thrust axis of a jet:



p_T relative to thrust axis:



Fragmentation function for 100GeV
jets embedded in central Pb+Pb
(using charged particles)

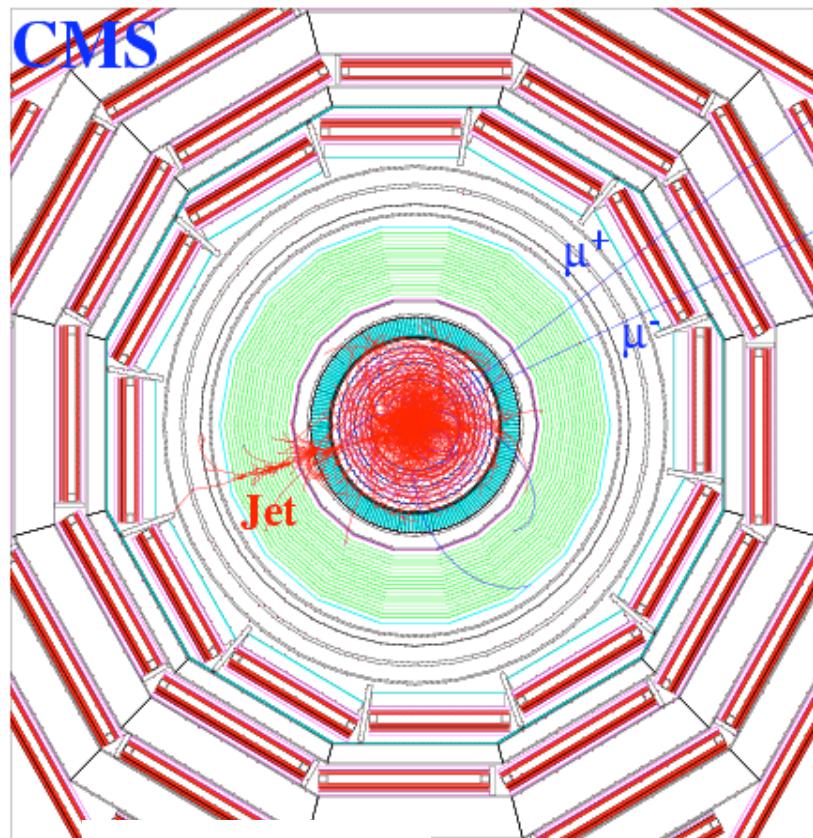


Balancing γ , γ^* or Z^0 vs Jets

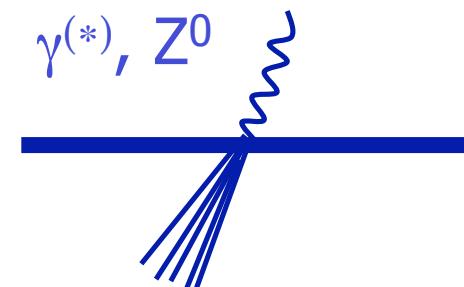
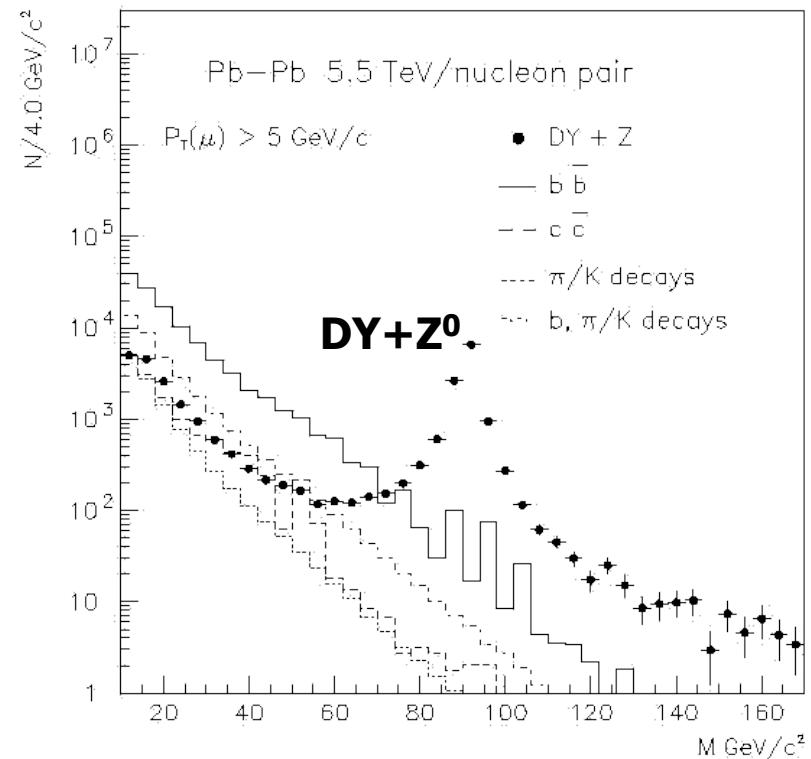


Z+jet event in the Heavy Ion collision

$dN_{ch} / dY = 5000$



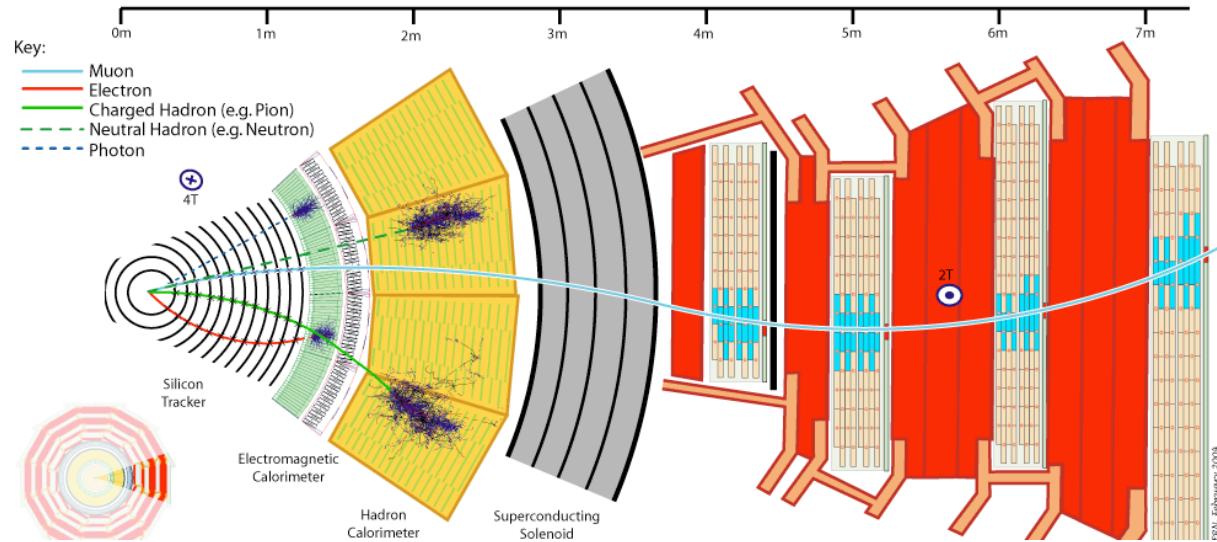
$P_T(Z) = E_T(\text{Jet}) = 100 \text{ GeV.}$



Handle on quark energy loss



Measuring Muons

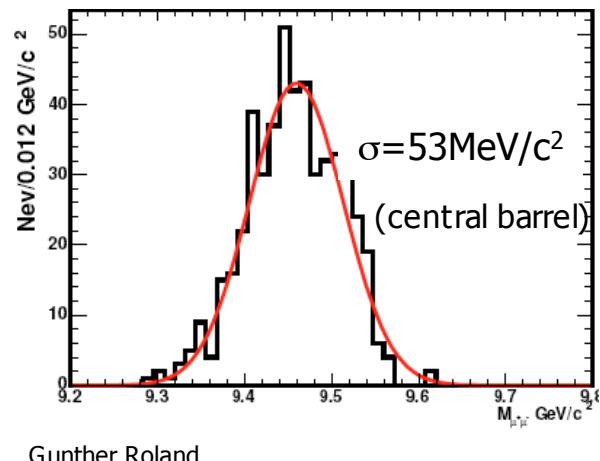
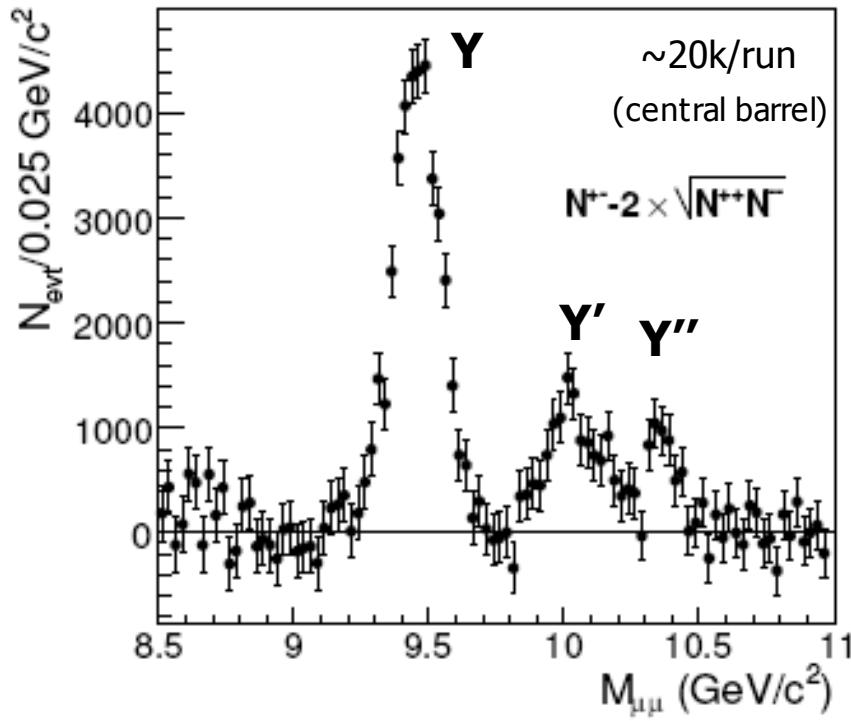


pp: TeV muons (4T field!); muon trigger; large coverage

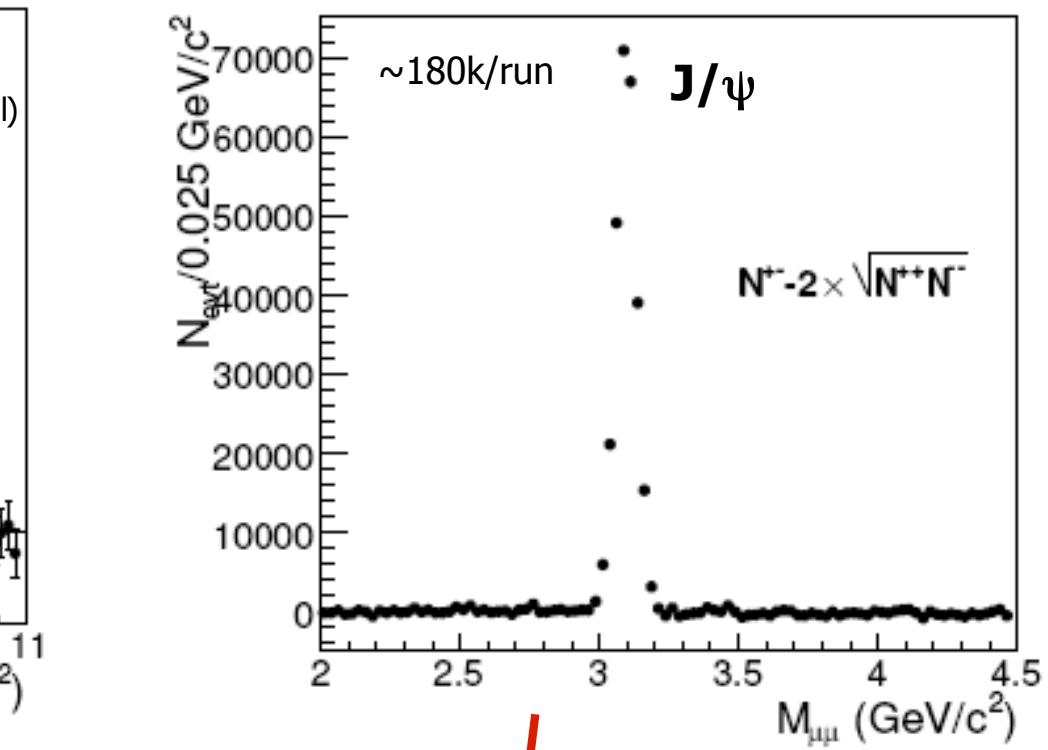
AA: Superb resolution; coverage; triggering
(caveat: low p_T cutoff)



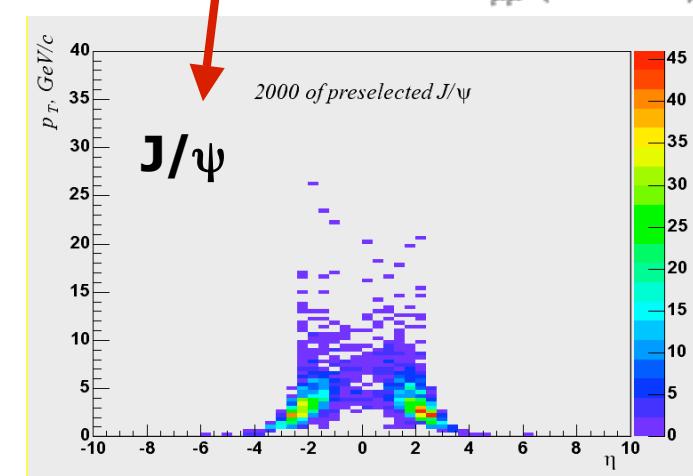
Quarkonia in CMS Heavy Ions

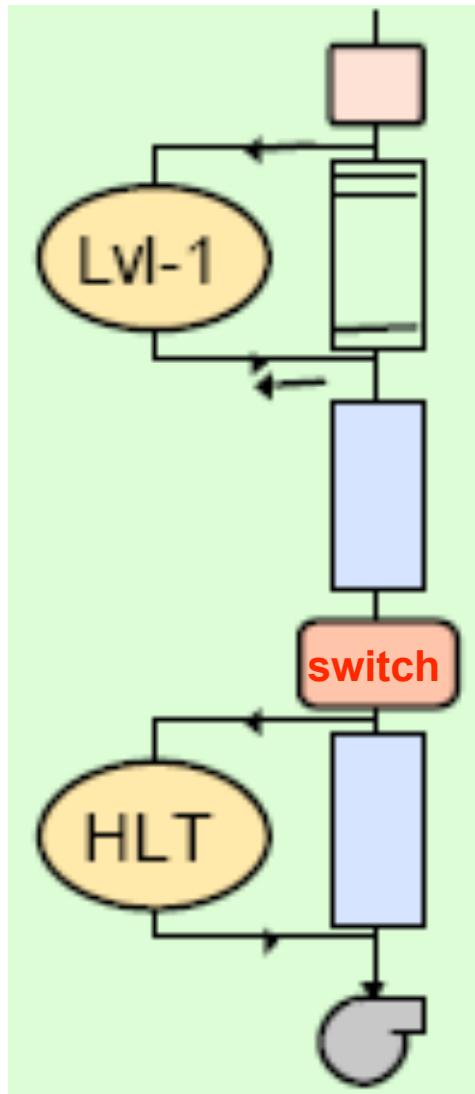


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Hard Probes 2006





Level 1 trigger

- Uses custom hardware
- Muon tracks + calorimeter information
- Decision after $\sim 3\mu\text{sec}$

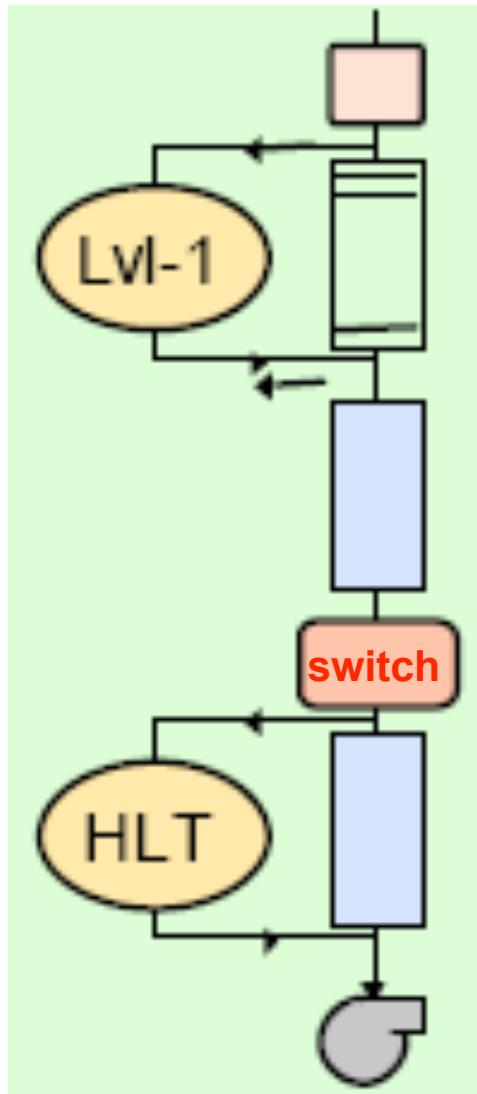
Level-1	p+p
Collision rate	1GHz
Event rate	32MHz
Output bandwidth	100 GByte/sec
Rejection	99.7%

High level Trigger

- ~ 1500 Linux servers ($\sim 10k$ CPU cores)
- Full event information available
- Runs “offline” algorithms

High Level Trigger	p+p
Input event rate	100kHz
Output bandwidth	225 MByte/sec
Output rate	150Hz
Rejection	99.85%

Trigger in Pb+Pb vs pp



Level 1 trigger

- Uses custom hardware
- Muon tracks + calorimeter information
- Decision after $\sim 3\mu\text{sec}$

Level-1	Pb+Pb	p+p
Collision rate	3kHz (8kHz peak)	1GHz
Event rate	3kHz (8kHz peak)	32MHz
Output bandwidth	100 GByte/sec	100 GByte/sec
Rejection	none	99.7%

High level Trigger

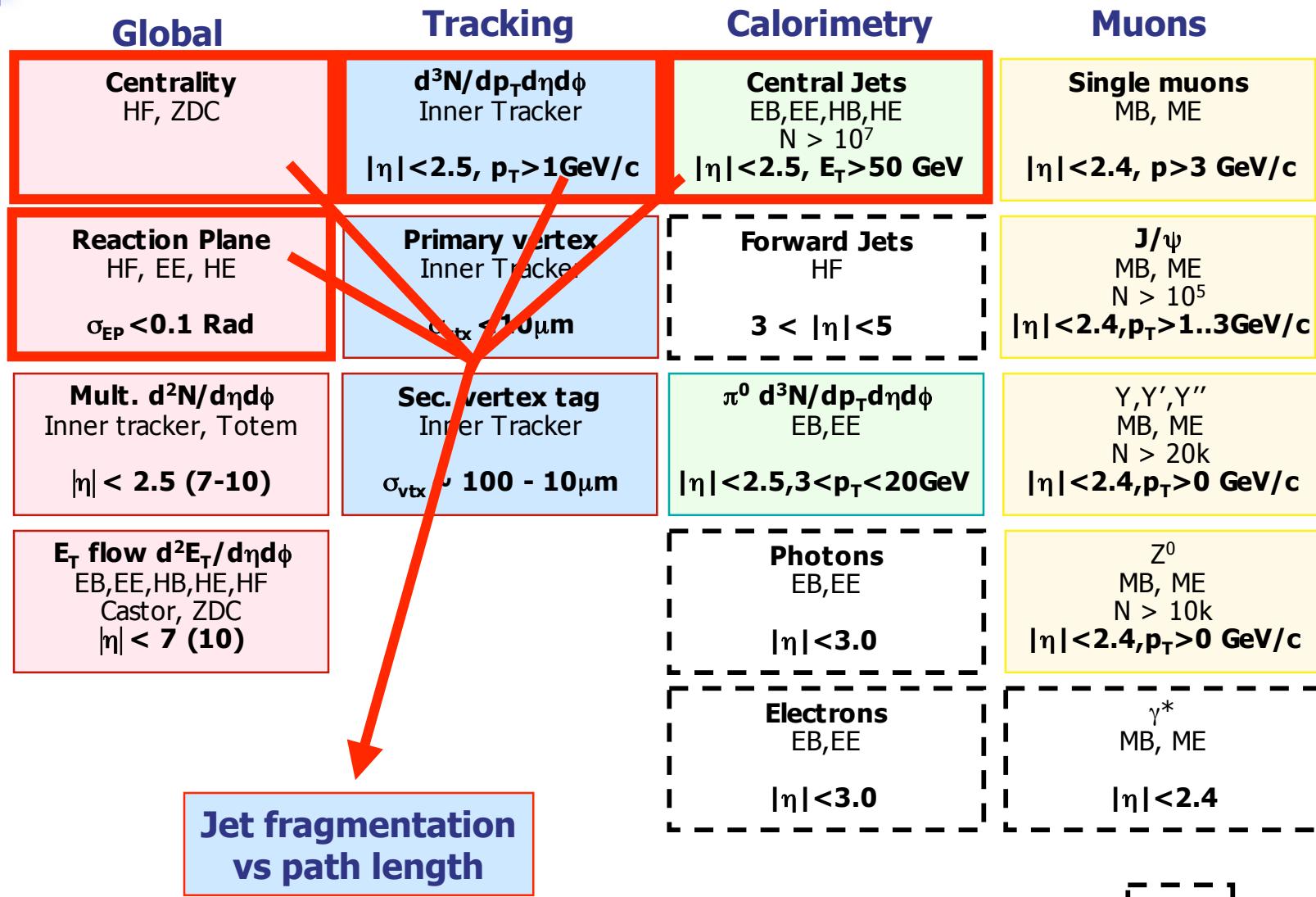
Main “hardware” task for CMS heavy ion running

- ~ 1500 Linux servers ($\sim 10k$ CPU cores)
- Full event information available
- Runs “offline” algorithms (~ 3 sec per HI event)

High Level Trigger	Pb+Pb	p+p
Input event rate	3kHz (8kHz peak)	100kHz
Output bandwidth	225 MByte/sec	225 MByte/sec
Output rate	10-100Hz	150Hz
Rejection	97-99.7%	99.85%



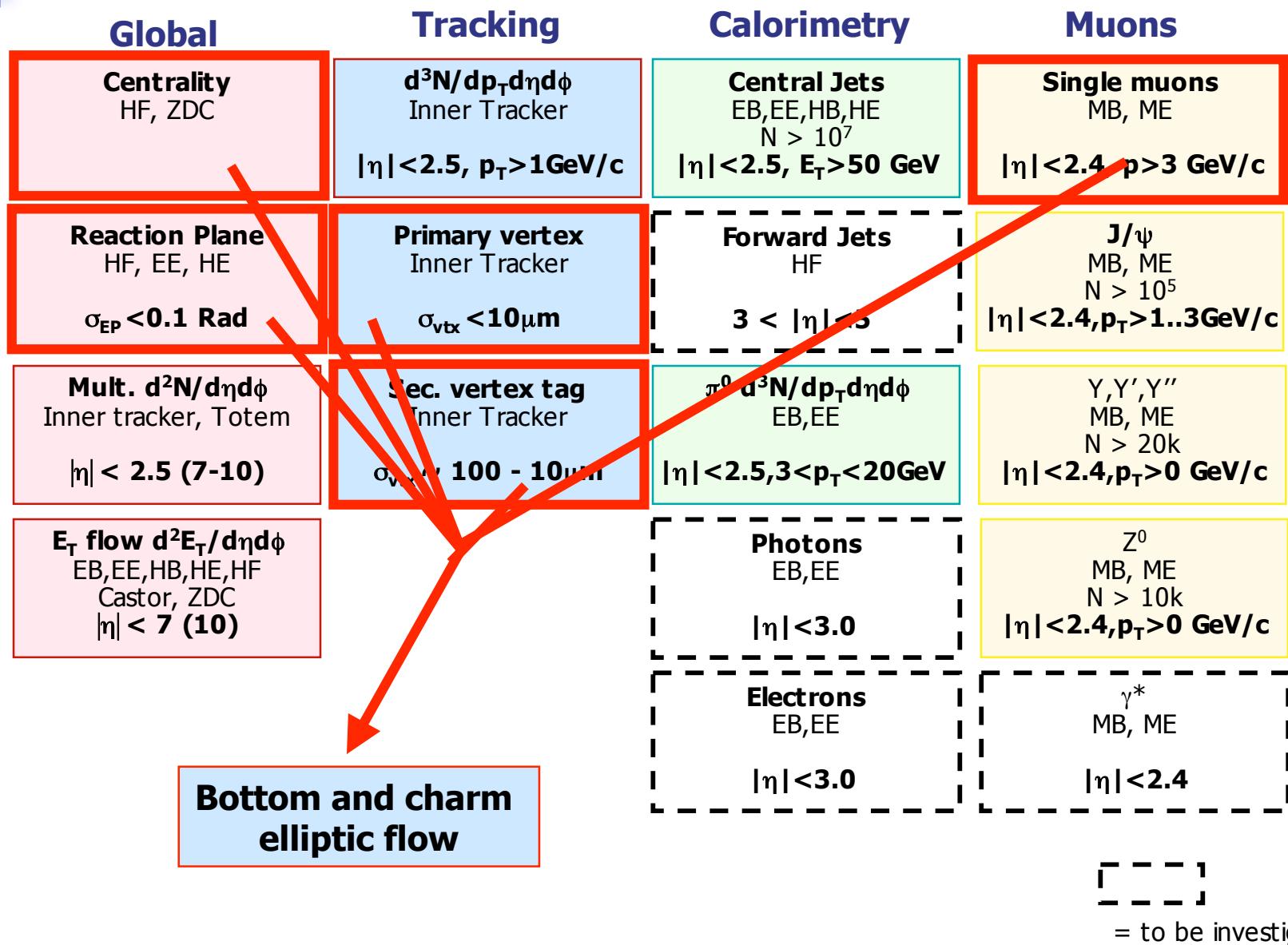
a kind of summary...



= to be investigated



a kind of summary...





a kind of summary...



Global	Tracking	Calorimetry	Muons
Centrality HF, ZDC $ \eta < 2.5, p_T > 1 \text{ GeV}/c$	$d^3N/dp_T d\eta d\phi$ Inner Tracker $ \eta < 2.5, p_T > 1 \text{ GeV}/c$	Central Jets EB,EE,HB,HE $N > 10^7$ $ \eta < 2.5, E_T > 50 \text{ GeV}$	Single muons MB, ME $ \eta < 2.4, p > 3 \text{ GeV}/c$
Reaction Plane HF, EE, HE $\sigma_{EP} < 0.1 \text{ Rad}$	Primary vertex Inner Tracker $\sigma_{vtx} < 10 \mu\text{m}$	Forward Jets HF $3 < \eta < 5$	J/ψ MB, ME $N > 10^5$ $ \eta < 2.4, p_T > 1..3 \text{ GeV}/c$
Mult. $d^2N/d\eta d\phi$ Inner tracker, Totem $ \eta < 2.5 (7-10)$	Sec. vertex tag Inner Tracker $\sigma_{vtx} \sim 100 - 10 \mu\text{m}$	$\pi^0 d^3N/dp_T d\eta d\phi$ EB,EE $ \eta < 2.5, 3 < p_T < 20 \text{ GeV}$	$\gamma, \gamma', \gamma''$ MB, ME $N > 20k$ $ \eta < 2.4, p_T > 0 \text{ GeV}/c$
E_T flow $d^2E_T/d\eta d\phi$ EB,EE,HB,HE,HF Castor, ZDC $ \eta < 7 (10)$		Photons EB,EE $ \eta < 3.0$	Z^0 MB, ME $N > 10k$ $ \eta < 2.4, p_T > 0 \text{ GeV}/c$
		Electrons EB,EE $ \eta < 3.0$	γ^* MB, ME $ \eta < 2.4$

**CMS@LHC: Abundant, well-defined high p_T objects
Connected to identified partons in a well-characterized medium**